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Menahem

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[54] **3 DEGREE OF FREEDOM HAND CONTROLLER**

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[73] Assignee: **Honeywell Inc.**, Minneapolis, Minn.

[21] Appl. No.: **655,740**

[22] Filed: **Feb. 14, 1991**

[51] **Int. Cl.**[5] **G05G 9/047**; B64C 13/04

[52] **U.S. Cl.** .... **74/471 XY**; 244/234; 244/236; 338/128

[58] **Field of Search** .... 74/471 XY; 200/6 A; 244/234, 236; 338/128

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[57] **ABSTRACT**

A hand controller which includes a hand grip having therein a gimble mechanism for allowing rotatory motion about three axes which intersect in the interior of the hand grip and from which motion transmitting members allow the motions about the three axes to be transmitted to remote pick off devices and also along which force feedback signals may be fedback to the gimble structure to provide the correct "feel" for the grip.

22 Claims, 3 Drawing Sheets

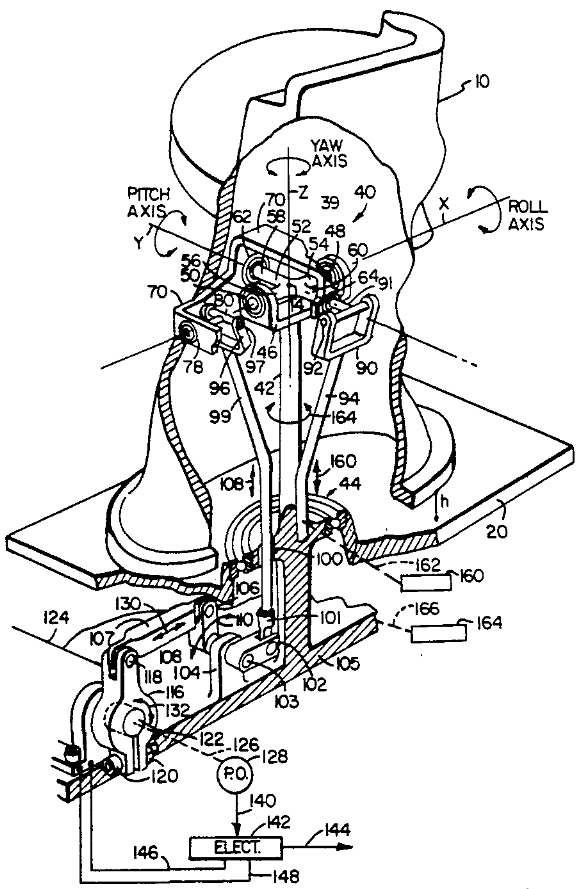
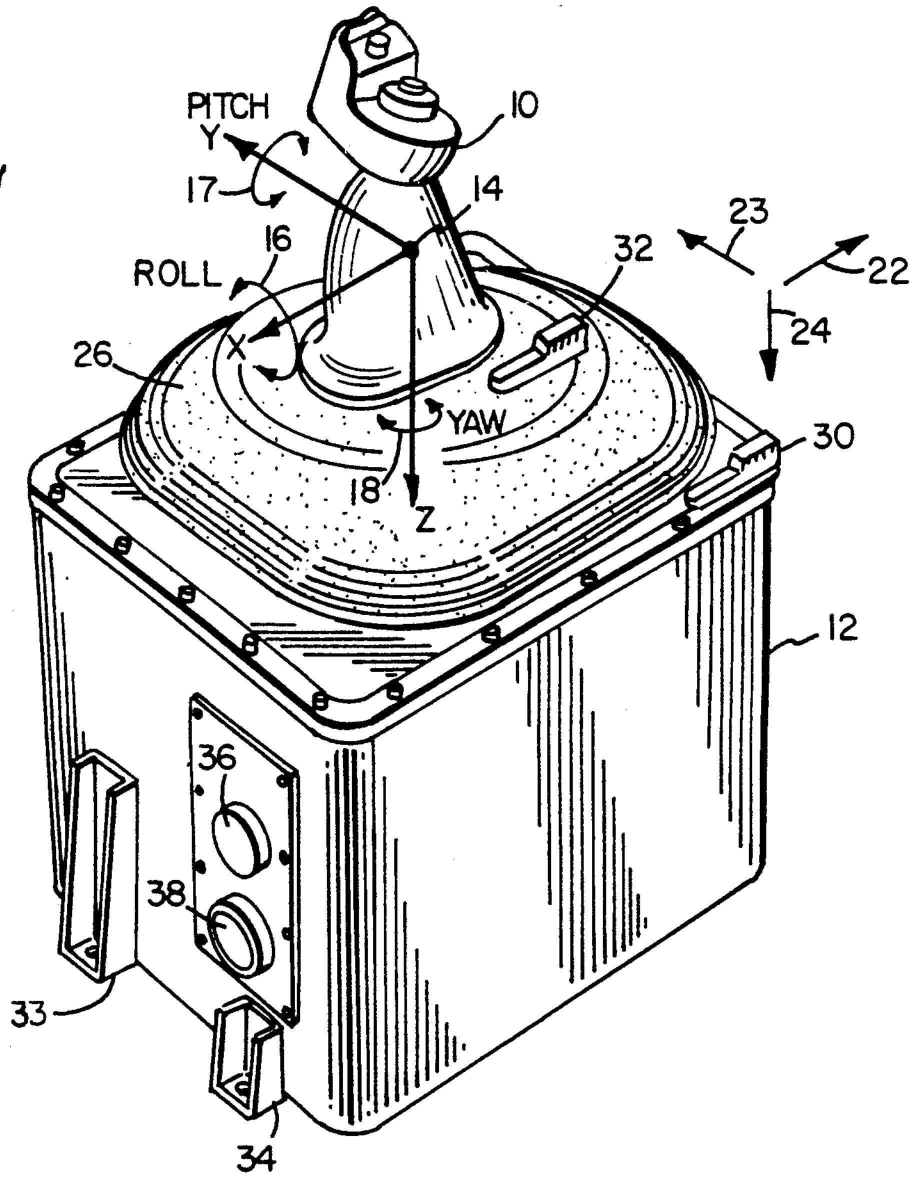


Fig. 1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Y
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ROLL
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YAW
18
Z
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38
33
34

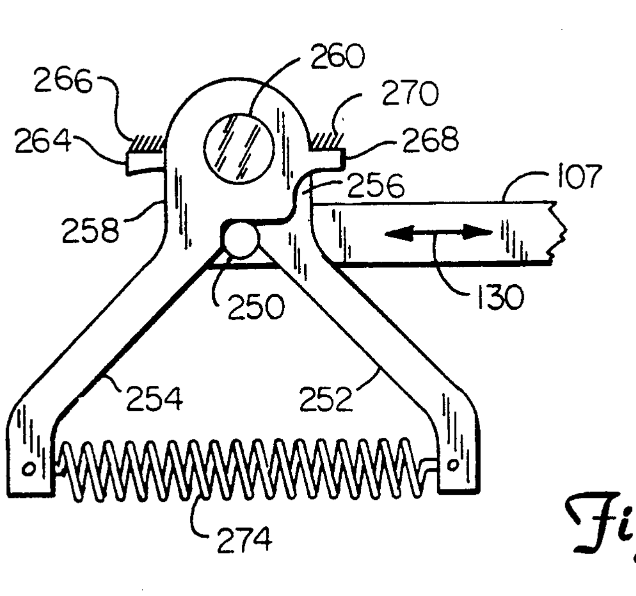
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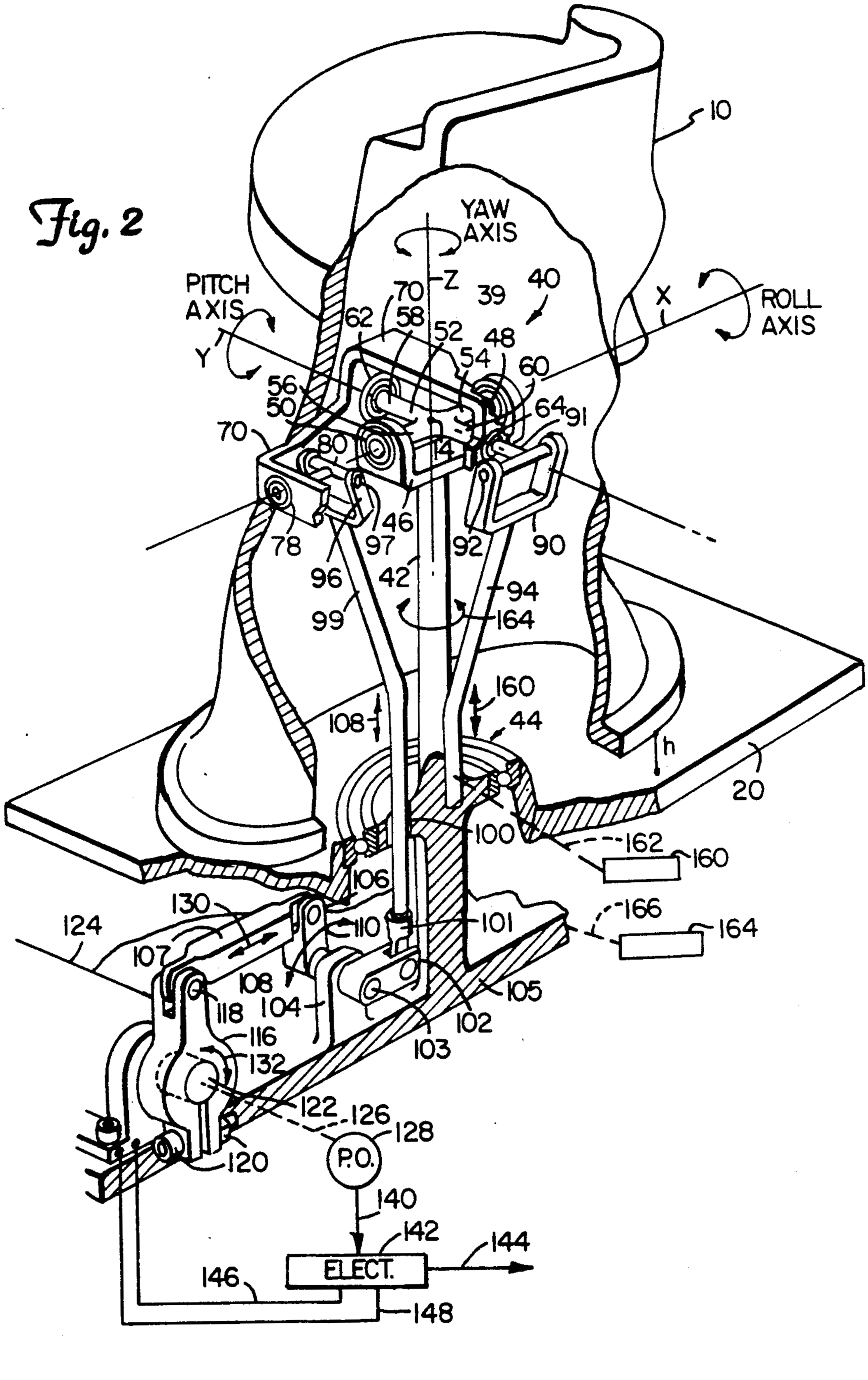
Fig. 5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AXIS
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62
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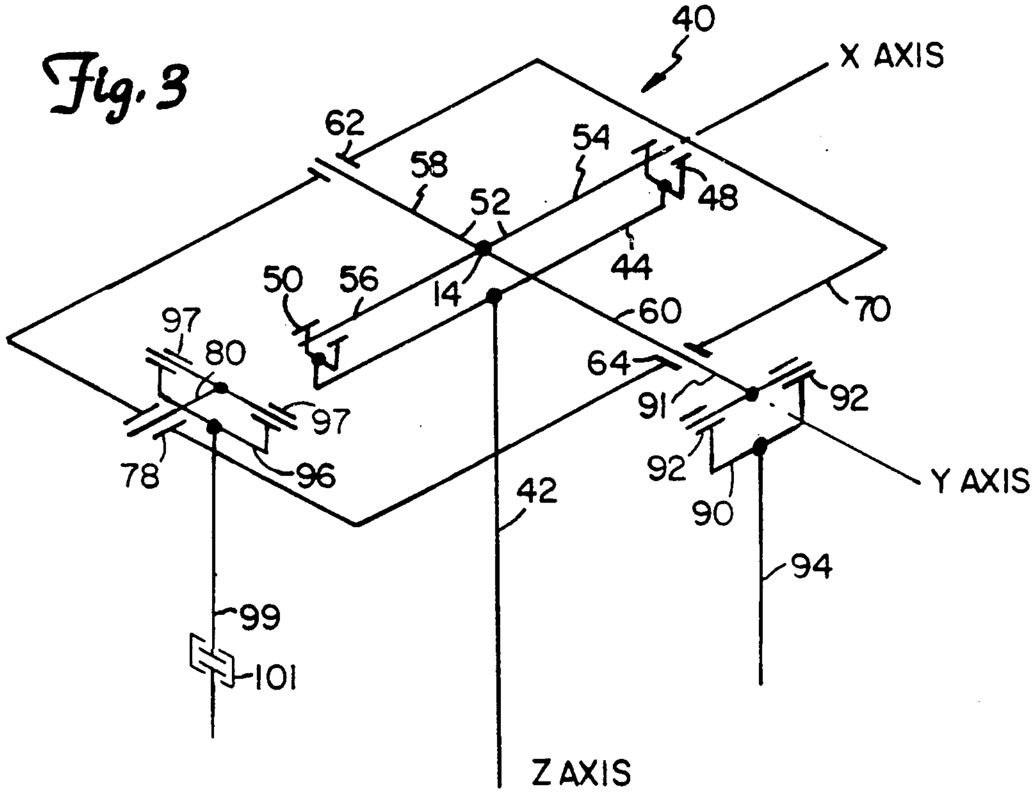
56
50
64
91
70
80
14
46
78
97
92
90
96
42
94
99
164
160
108
44
h
20
100
162
160
106
130
124
110
101
166
164
107
108
104
105
118
102
116
103
132
122
126
128
P.O.
120
140
142
144
ELECT.
146
148

Fig. 2

Fig. 3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62
58
54
52
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44
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56
14
60
70
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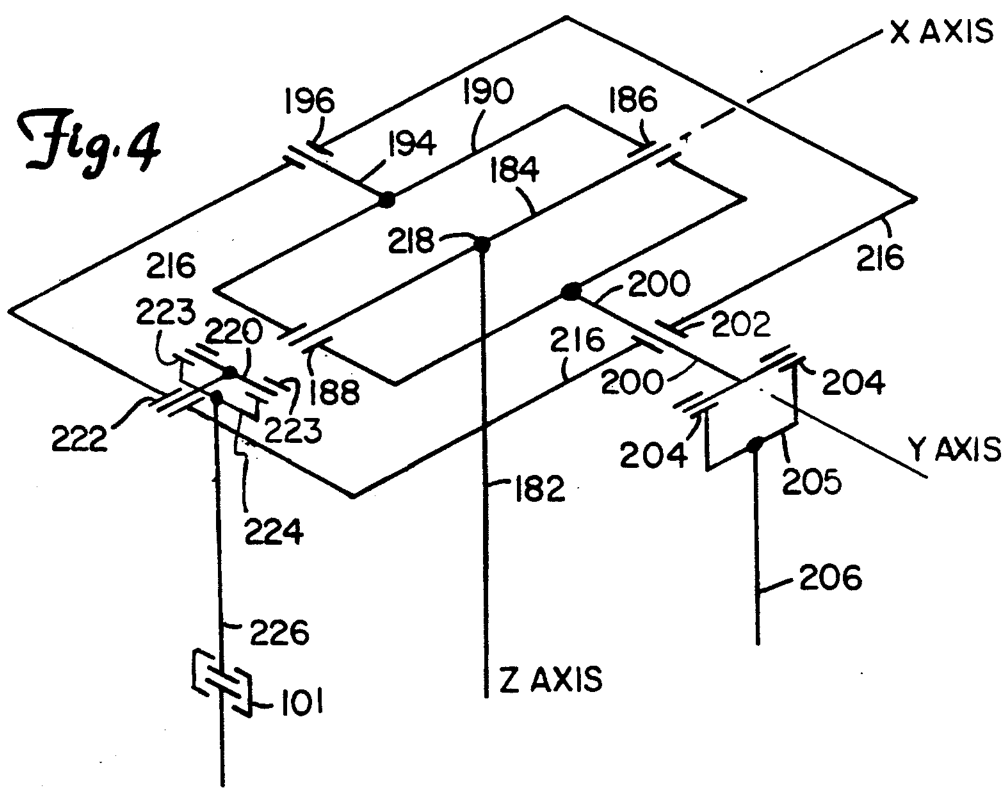
92
97
92
78
96
Y AXIS
42
90
94
99
101
Z AXIS

Fig. 4


X AXIS
196
190
186
194
184
218
216
216
200
223
220
202
216
188
200
204
222
223
204
Y AXIS
205
182
224
206
226
101
Z AXIS

3 DEGREE OF FREEDOM HAND CONTROLLER

UNITED STATES GOVERNMENT RIGHTS

The invention described herein was made in the performance of work under NASA Contract No. NAS9-18200, and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, as amended [42 U.S.C. 2457].

BACKGROUND OF THE INVENTION

The present invention relates to controllers and more particularly to hand operated controllers for operating remote systems such cranes, robot arms, air or space craft, free flyers and the like.

A number of hand controllers exist in the prior art designed for controlling robots, air craft or space craft and having specific features useful for particular applications. For example, in the Wyllie U.S Pat. No. 4,913,000, Wyllie U.S. Pat. No. 3,914,976 and the Hegg U.S. Pat. No. 4,895,039 all assigned to the assignee of the present invention, a wrist action hand grip for 3 degrees of freedom and a forearm grip for providing additional degrees of freedom is shown and has special utility in helicopter control. Cross coupling between the hand controller and the forearm controller is avoided by having the hand controller mounted on the same apparatus that carries the forearm apparatus so that motion of the forearm does not effect motion of the hand and vice versa. The hand controller itself is described in the Wyllie patents as a standard prior art device and such grips like that shown in U.S. Pat. No. 4,895,039 above, usually do not have all three of the axes passing through a common point. Accordingly, some cross coupling can occur about the offset axis. Furthermore, mounting the hand controller at the end of the forearm control box, as shown in the above mentioned patents, provides a rather lengthy control mechanism which, in a space craft, extends too far into the space occupied by the user than may be desired.

While hand controllers having all three axes passing through a common point located within the hand grip itself are not completely unknown in the prior art as, for example, U.S. Pat. No. 4,555,960 issued to Michael King on Dec. 3, 1985, such controllers are faced with other difficulties which make them impractical. For example, because a hand controller grip is limited in size so as to accommodate the human hand, it has been heretofore impossible to get all of the mechanism necessary for producing control outputs and force feedback inputs to control three different degrees of freedom with the desired "feel" all within the hand grip itself. In the above mentioned King patent, the yaw axis has an extension from the hand grip to a remote housing where a large enough force feedback device could be located, but with regard to pitch and roll, tiny scissor/spring mechanisms are shown within the hand grip itself to attempt to provide force feedback for the pitch and roll axes. Unfortunately, they are too small to work effectively which is always the case because electric torque generating motors and scissor/ spring mechanism large enough for such purposes are too large to fit within the hand grip. When attempts are made to locate the force producing motors or scissor/spring mechanisms remote from the hand grip so that they can be large enough to provide the desired "feel", the pitch and/or roll axes are then also remote from the hand grip with the result that the three axes do not intersect inside of the hand grip and cross coupling can occur.

SUMMARY OF THE INVENTION

The present invention provides a 3 degree of freedom hand grip in which all three axes intersect within the cavity of the grip to prevent cross coupling and force feedback is provided from remotely located force producing devices through a unique connection arrangement to give the correct "feel" for pitch and roll. More specificaliy, the motions produced by the operator about the roll and pitch axes which intersect with the yaw axis in the hand grip are transferred via motion transmitting members which run from the grip down generally parallel to but displaced from the yaw axis to a housing located below the hand grip and through suitable mechanism therein operate to provide the necessary force feedback either from sufficiently large scissor/spring devices or torque generating motors. The suitable mechanism also includes a lever arm arrangement to provide for force multiplication. The same motion transmitting members may also be used to produce the required output signals. The housing itself may be designed to contain one or more additional degrees of freedom in a manner similar to that shown in the above mentioned Wyllie and Hegg patents although in the present invention the hand grip is mounted above the cabinet so that resulting apparatus is not as long as was the case in these patents and does not extend into the usable space of a space craft nearly as much.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an overall view of the hand controller mounted on a housing as contemplated in the present invention;

FIG. **2** shows a cutaway view of the hand controller and the three axes intersection contained therein and shows a schematic representation of electronics necessary to provide output signals and

FIG. **3** is a schematic representation of the gimble mechanism 2; and,

FIG. **4** is an schematic representation of an alternate gimble mechanism for use within the hand controller; and,

FIG. **5** shows a scissor/spring device suitable for use in the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. **1**, a three degree freedom hand controller grip **10** of the present invention is shown mounted on a housing **12** which in turn is attached to a frame such as the interior structure of a space station, (not shown). Unlike the prior art discussed above, the grip **10** is not mounted on a forearm holding device and accordingly, will not extend lengthwise as far into the cabin of the space craft as the prior art.

Hand grip **10** is adapted to be grasped by the hand of a controller and to move about three orthogonal axes, X, Y and Z, in a rotary fashion. The X, Y and Z axes may be considered the roll, pitch and yaw axes respectively, and are shown intersecting at a point **14** which is rather centrally located inside a cavity in the grip **10**. When used to control a space craft or a free flying device, motion of the grip **10** about the three axes may be used to produce control of the roll, pitch and yaw motions of the craft respectively. In other words, pushing grip **10** to the right or the left about the X axis will

produce a roll motion as shown by double ended arrow **16**, pushing the grip **10** forward or backwards about Y axis will produce pitch motion as shown by double ended arrow **17** and twisting grip **10** about the Z axis will produce yaw motion as shown by double ended arrow **18**. Because the three axes meet at a single point **14** there is no cross coupling between motions about any of the axes.

Grip **10** may be fastened to a movable member **20**, (in a manner best seen in FIG. **2**). Member **20** member may be mounted in housing **12** to move with the motions of the grip **10** in up to three linear directions shown by arrows **22**, **23** and **24**. The additional three degrees of freedom provided by motions along directions shown by arrows **22**, **23** and **24** may be produced by a mechanism shown in the above mentioned Hegg and Wyllie patents or, in the preferred embodiment by apparatus shown in a co-pending application Ser. No. 07/738,255 filed Jul. 30, 1991 in the name of Israel Menahem and James Bacon which is assigned to the assignee of the present invention. The directions shown by arrows **22**, **23** and **24** may be parallel to axes X, Y and Z, as shown, although this is not required. The movable member **20** (not seen in FIG. **1**) is mounted to the housing **12** by a flexible cover **26** so as to permit the motion in all of the directions required for the hand controller, i.e., pitch, roll, yaw and, if desired, directions shown by arrows **22**, **23** and **24**. If member **20** is mounted for motion in a relatively frictionless manner, then a linear force produced by the operator's hand through point **14** along the X, Y, Z directions will produce linear motions along the directions shown by arrows **22**, **23** and **24** respectively with no cross coupling to the motions about pitch, yaw and roll axes. If it is desired to use less than six degrees of freedom, locking switches such as shown in FIG. **1** with reference numeral **30** may be moved to prevent motion in the directions shown by arrows **22**, **23** or **24**, respectively. Alternately, or simultaneously, a locking switch shown with reference numeral **32** may be moved to prevent motion in the directions shown by arrows **16**, **17** and **18** respectively.

In order to give the operator the proper "feel" for grip **10**, it is customary to provide some sort of force feedback which opposes the motion produced by the operators hand. This force feedback can be a passive one such as is provided by scissor/springs described in the above mentioned U.S. Pat. Nos. 4,895,039 and 4,555,960 or by torque motors as will be described in connection with the preferred embodiment of the present invention as seen in FIG. **2**.

Scissor/spring mechanisms and torque motors large enough to provide sufficient force occupy considerable amount of space and the interior of grip **10** does not have enough space to allow them to be placed therein. Accordingly, the force applying means for all three axes are located outside of the grip and the force is transmitted back to the grip through unique motion transmitting members and couplings. The force able to be applied is further enhanced by offsetting the force transmitting members for the pitch and roll axes so that a lever arm is produced as will be described in connection with FIG. **2**. The motion transmitting members extend from the grip **10** into the housing **12** where there is sufficient room to accommodate larger scissor/springs or torque motors. The housing **12** is shown in FIG. **1** as having mounting members **33** and **34** attached to one side and these are used for attaching the housing to the craft where it is being used. Also shown are electrical connectors shown by reference numeral **36** and **38** which are used for bringing signals into and out of the housing **12** for use in control and feedback.

Referring now to FIG. **2**, the hand grip located a distance "h" above plate **20** is shown in cutaway so as to expose a cavity **39** with a gimble arrangement **40** in the interior part thereof. A rotatable shaft **42** is shown extending along the Z or yaw axis outside of grip **10** through a bearing **44** in plate **20** and into the housing **12** (not shown in FIG. **2**). A U-shaped yoke **46** is fastened to the end of shaft **42** and the upwardly extending ends thereof contain a pair of bearings **48** and **50** the centers of which lie along the X or roll axis. An "X" shaped member **52** has first and second legs **54** and **56** mounted in the inner race of bearings **48** and **50**, respectively, for rotation about the X axis or roll axis. "X" shaped member **52** also has third and fourth legs **58** and **60** perpendicular to the first and second legs **54** and **56** and these are mounted in the inner race of a pair of bearings **62** and **64**, respectively, for rotation about the Y or pitch axis. The legs **58** and **60** lie along the Y axis and, as mentioned, the legs **54** and **56** lie along the X axis while the rotatable shaft **42** lies along the Z axis so that, as seen, all three axes X, Y and Z meet at a point **14** in the center of the "X" shaped member **52**.

Bearings **62** and **64** are mounted in a frame member **70** which extends over the top of and around the left side of "X" shaped member **52**. On the left side, frame member **70** also is connected to the outer race of a bearing **78** the inner race of which is connected to a T-shaft **80**. Bearing **78** and shaft **80** lie along the X axis. Frame member **70** is attached to the interior portion of the grip **10** and any motions of grip **10** imparted thereto by the operator will be passed to the frame **70** as will be described. It will be understood that grip **10** is loosely fastened to the housing **12** of FIG. **1** by a flexible cover **26** and that member **20** is mounted in housing **12** by a mechanism which permits motion in the directions **22**, **23** and **24** with respect thereto. Accordingly, motions of member **20** in directions **22**, **23** and **24** carry grip **10** along but motions of grip **10** about the roll, pitch and yaw axes are independent of member **20**.

A U-shaped member **90** is rotatably attached to a T-shaft **91** through a pair of bearings **92**. The T-shaft **91** extends into frame member **70** and is rotatably attached thereto by bearing **64**. U-shaped member **90** is fixed to a motion transmitting shaft **94** which extends outside of grip **10** through an aperture in plate **20** (not seen in FIG. **2**) so that motion transmitting member **94** may move up and down in a more or less parallel relationship to the Z axis. In similar fashion, a U-shaped member **96** is rotatably attached to the outer race of a pair of bearings **97** the inner race of which carries T-shaft **80**. U-shaped member **96** is fixed to a motion transmitting shaft **99** which extends outside of grip **10** through an aperture **100** in plate **20** so that motion transmitting member **99** also moves up and down in a more or less parallel relationship to the Z axis. The aperture (not seen) for motion transmitting member **94** would be like aperture **100** for motion transmitting member **99**. It should be noted that the upper ends of motion transmitting members **94** and **99** are offset from the Z axis by an amount which depends on the position of bearings **64** and **78** and this allows a greater force to be applied to the frame member **70** because of the lever arm equal to the offset distance. This distance can be varied by designing the frame member **70** for various offset distances so as to provide very accurate control of the feedback forces

The gimble arrangement above described may also be seen in schematic form in FIG. 3 which will be described below.

Rotatable shaft **42** and motion transmitting shafts **94** and **99** are operable to bring motions of the gimble mechanism **40** out from the grip **10** down to signal pick off devices in housing **12** and to also bring feedback forces from torque motors in housing **12** back to the gimble device **40** as will now be described. For simplicity, only one such connection has been shown in FIG. 2. The shaft **99** is connected near its lower end to the inner race of a thrust bearing **101** the outer race of which is connected to an attachment member **102** the other end of which is connected to a shaft **103** which is journaled to an upright extension **104** of a plate **105** connected to and movable with the rotatable shaft **42**. Thus, plate **105** and all the apparatus attached to it move with member **20** in the x, y and z directions and are rotatable about the Z axis with rotations of shaft **42**.

Shaft **103**, on the other side of extension **104**, is connected to an upright extension **106** pinned to one end of a generally horizontal member **107**. When shaft **100** moves up and down in FIG. 2, in a direction shown by a double ended arrow **108**, such motion will be accompanied by a rotatory motion of member **102**, shaft **103** and extension **106** in a direction shown by double ended arrow **110**. The other end of horizontal member **107** is connected to a clamping device **116** by means of a journal **118**. Clamping device **116** is tightened by means of a nut and bolt **120** so as to clamp to a shaft **122** connected to the rotor of a torque motor **124** mounted on plate **105**. Shaft **122** is also connected by a mechanical connection shown by dashed lines **126** to a pick off device **128** which may be a resolver or variable resistance device, for example, and which operates to produce an output in accordance with rotation of shaft **122**. It is seen that as member **102** rotates in a direction shown of arrow **110** member **107** will move back and forth in the direction shown by double ended arrow **130** which motion will impart rotatory motion to the clamping device **116**, shaft **122**, mechanical connection **126** and the pick off device **128** in a direction shown by double ended arrow **132**. Rotation of pick off device **128** causes it to change its output. The output of pick off device **128** is shown by arrow **140** which is connected to various signal conditioning and amplifying circuits found in an electronics package **142**. The amount of up and down motion of member **99** is thus converted to an output signal by the linkage above described and the pick off device **128**. The electronics package **142** operates to produce a suitable output signal as shown by arrow **144** to control the crane, robotic device or the control surfaces or thrusters of a craft to be controlled (not shown).

Electronic package **142** also produces output signals on a pair of connections **146** and **148** which are presented to the torque motor **124** and are operable to produce torque on shaft **122** in proportion to the output of pick off device **128**. Such torque will be in the opposite direction to the motion above described. Thus, torque motor **124** will produce an oppositely affecting torque through the clamping means **116**, members **107**, **106** and **102** to motion transmitting member **99** and back to grip **10** through bearing **78** and shaft **80** so as to produce a counter force on frame member **70** which force is enhance by the lever arm resulting from the off set of bearing **78** from the Z axis. More specifically, if the operator were to move his hand and grip **10** forward around the pitch axis Y, motion transmitting member **99** would move upwardly thus causing members **102** and **106** to move in a counter clockwise direction and member **107** would move to the left. This would cause clamping device **116** and shaft **122** to move in a counter clockwise direction and the signal produced by pick off device **128** would be fed back via electronics **142** and connections **146** and **148** to motor **124** to produce a counter acting torque on shaft **122** which would then tend to move fastening member **116** in a clockwise direction, member **107** to the right, members **106** and **102** in a clockwise direction and motion transmitting member **99** downwardly. Thus, the operator would sense resistance to the his motion around the pitch axis so as to give him the "feel" of the stick. This force will be significantly larger than previously possible because a larger motor can be used and because of the lever arm produced by the offset of bearing **78** from the Z axis.

While not described in connection with FIG. 2, similar torque motors and pick offs (shown by box **160** be connected in similar manner to motion transmitting shaft **94** as shown by dashed line **162** while rotatable shaft **42** may be direct drive connected to similar force generating means **164** by a connection shown by dashed lines **166**. Accordingly, operator produced motions about the roll axis X and the yaw axis Z will also produce feedback torques to provide the proper "feel" to the grip **10** about all three axes.

It is also seen that when the operator moves grip **10** around the pitch axis Y, no motion of X-shaped member **52** results and accordingly, no motion of shafts **42** and **94**. On the other hand, if the operator turns the grip **10** left and right about the roll axis X, then up and down motion of motion transmitting member **94** along the direction shown by arrow **160** results but since bearings **48** and **50** and shaft **80** lie along the roll axis X, no motion of shafts **42** and **99** result. Similarly, since plate **105** and all of the apparatus attached thereto turn with motion of grip **10** about the yaw axis, such motion, although carrying the "X"-shaped member **52** in a horizontal plane about the Z axis, does not produce up and down motion of either shafts **94** or **100**. Thus cross coupling is avoided. When combinations of roll and pitch occur simultaneously, motion transmitting shaft **100** rotates about its central axis which therefore requires the thrust bearing **101** to be located on the linkage as shown in FIG. 2.

For clarity, the gimble arrangement of FIG. **2** is redrawn schematically in FIG. **3** and the same reference numerals used to describe like elements in FIG. **2** are employed. In FIG. **3** it is seen that the U shaped member **44** is carried by the vertical rotatable shaft **42** and carries the pair of bearings **48** and **50**. The X shaped member **52** has legs **54** and **56** journaled in bearings **48** and **50** respectively and has legs **58** and **60** journaled in bearings **62** and **64** respectively carried by frame member **70**. Bearing **78** is carried on the left side of frame member **70** and T-shaft **80** is journaled in the bearing **78**. A U-shaped member **96** carries bearings **97** which rotatably hold the ends of T-shaft **80**. U-shaped member **96** is connected to motion transmitting member **99** and member **99** extends through thrust bearing **101** a to the housing **12** as described above. In similar manner, motion transmitting member **94** is connected to U-shaped member **90** and, through bearings **92** is connected to T-shaft **91** which is journaled in bearing **64**.

While the gimbled arrangement **40** shown in FIGS. **2** and **3** is the preferred embodiment, FIG. **4** shows an alternate arrangement in schematic form. In FIG. **4**, a

rotatable shaft **182** is shown connected to a cross bar **184** which passes through the center of bearings **186** and **188** mounted on a first rectangular shaped member **190**. Bearings and **188** lie along the X axis. Half way around rectangular member **190** from bearing **186** and **188**, a shaft extension **194** is connected through a bearing **196** and, on the opposite side, a T-shaft **200** is connected through a bearing **202**. Bearings **196** and **202** lie along the Y axis. The T-shaft **200** is also journaled in the inner race of a pair of bearings **204** and a U-shaped member **205** is connected to the outer race of bearings **204**. A shaft **206** is connected to U-shaped member **205** and comprises the motion transmitting member for the roll axis. On the left side of rectangular shaped member **216** is a T-shaft **220** which is connected to the inner race of a bearing **222** the outer race of which is connected to the rectangular shaped member **216**. Bearing **222** is also along the X axis. T-shaft **220** is also journaled in a pair of bearings **223** and a U-shaped member **224** is connected to the outer race of bearings **223**. A shaft **226** is connected to U-shaped member **224** and comprises the motion transmitting member for the pitch axis which extends down to the housing through the thrust bearing **101** as was the case in FIGS. **2** and **3**. As seen, the cross bar **184**, bearings **186** and **188** as well as bearing **222** lie along the X axis while bearings **196** and **202** lie along the Y axis. Rotatable shaft **182** lies along the Z axis and all three axes intersect at a common point **218** which will be inside a grip like grip **10** of FIGS. **1** and **2**. Similarly to the arrangement shown in FIG. **2** the outer O-shaped member **216** would be fastened to the grip **10** and it is seen that motion from left to right about the X axis will produce motion of transmitting member **226** up and down but produce no motion of motion transmitting member **228** or rotatable member **182**. Similarly, pitch motion around the Y axis will cause up and down motion of motion transmitting member **226** but no motion transmitting member **206** or rotatable member **182**. Finally, the yaw motion around axis Z will produce rotatory motion of shaft **182** about the Z axis but no up and down motion of transmitting members **206** and **226** although they will rotate around the Z axis as was the case in FIG. **2**. As in the previous gimble arrangement, the forces applied by the motion transmitting members **206** and **226** are passed down to a housing where sufficiently large force producing devices can be located. The arrangement may be the same as described in connection with FIG. **2**. Finally, as seen, the feedback forces applied through transmitting members **182** and **226** are multiplied with a lever arm which exists because of the offset of bearings **202** and **222** from the Z axis.

In place of the electronic package **142** connections **146** and **148** and torque motor **124** along with the various connections described in connection with FIG. **2** to provide a force feedback, the spring/scissors mechanism of FIG. **5** may be employed. In FIG. **5**, the horizontal member **107** movable int he direction shown by double ended arrow **130** comprises the same elements as were used in connection with FIG. **2**. Member **107** is connected to a pin **250** which lies between a leg **252** and a leg **254** of independently rotatable members **256** and **258** respectively, mounted on a shaft **260**. Member **256** has a horizontal extension **264** which normally bears against an abutment shown by hash lines **266** and member **258** has a horizontal extension **268** which normally bearings against an abutment shown by hash lines **270**. The lower ends of legs **252** and **254** are joined by a tension spring **274** which operates to normally hold the legs in a closed position around pin **250**. However, as member **107** moves in either of the directions **130** this motion will be accompanied by one of the legs **252** or **254** moving away from the position shown and acting against the tension of spring **274** to rotate around shaft **260**. As it does so the force of spring **274** will increase so as to put an increasing feedback tension on member **170** and thus give the "feel" feedback to the operator.

It is therefore seen that I have provided a unique three degree of freedom hand controller operable to impart motion around first, second and third axes which intersect in the center thereof so as to avoid cross coupling and from which connection members extend to motion pick off and feedback devices located where they have more room to be mounted. It is also seen that the feedback forces can be very accurately adjusted by careful design of the offset lever arms and that the apparatus is compact in size and will not extend unnecessarily into the space usable by space pilots in the cockpit of their craft. Many changes will occur to those skilled in the art. For example, other gimble arrangements may be devised and couplings to provide force feedback from the remote housing to the gimble arranged. The U-shaped members such as **90**, **96** **205** and **224** attached to the motion transmitting members may be located on opposite sides from the positions shown in the drawings or, on both sides if desired. In fact, the motion transmitting members may be cables in which case it may be preferable to have connections on both sides of the gimble arrangements. The pick offs, while shown remotely located in the preferred embodiment may be placed in the grip as was done in the above mentioned U.S. Pat. No. 4,555,960 and while they may be potentiometers or resolvers, as described, may alternately be other types of signal transducers. It is therefore seen that although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. Three degrees of freedom hand controller apparatus including a grip for use by a controller's hand to produce output motion representative of turning motion of the hand about first, second and third mutually perpendicular axes intersecting at a point inside the grip, comprising:

first rotatable means (**46**) mounted within the grip for rotation about the first axis when the controller's hand moves the grip about the first axis;

second rotatable means (**52**) mounted within the grip on the first rotatable means for rotation about the second axis when the controller's hand moves the grip about the second axis;

third rotatable means (**70**) mounted within the grip on the second rotatable means for rotation about the third axis when the controller's hand moves the grip about the third axis;

first motion transmitting means connected to the first rotatable means and extending outside the grip to transmit rotary motion of the first rotatable means;

second motion transmitting means connected to the second rotatable means and extending outside the grip to transmit rotary motion of the second rotatable means; and

third motion transmitting means connected to the third rotatable means and extending outside the

grip to transmit rotary motion of the third rotatable means.

2. Apparatus according to claim **1** further including signal producing means connected to the first, second and third motion transmitting means to produce an electrical signal indicative of the motion of the first, second and third rotatable means about the first, second and third axes respectively.

3. Apparatus according to claim **1** wherein the first motion transmitting means comprises a first elongated member (**42**) fixed to the first rotatable member and extending generally along the first axis, the second motion transmitting means comprises a second elongated member (**94**) connected to the second rotatable member and extending generally parallel to the first axis and the third motion transmitting means comprises a third elongated member (**99**) connected to the third rotatable member and extending generally parallel to the first axis.

4. Apparatus according to claim **3** wherein the motion transmitted by the first elongated member is rotary, and the motions transmitted by the second and third elongated members is linear, the signal producing means operates to convert rotary motion to electrical signals and further including modifying means to convert the linear motion transmitted by the second and third motion transmitting means to rotary motion for use by the signal producing means.

5. Apparatus according to claim **1** wherein the three degree of freedom hand controller is connected to member means that is mounted for low friction linear movement in a first direction, a force applied to the grip generally through the point of intersection of the three axes causing motion of the member means along the first direction without motion of the grip about the first, second or third axis.

6. Apparatus according to claim **1** further including force feedback means connected to the first, second and third motion transmitting means and operable to provide a force tending to oppose any motion of the first, second and third rotatable means about the first second and third axes respectively.

7. Apparatus according to claim **6** wherein the force feedback means comprises first, second and third scissor spring mechanisms (FIG. **5**) connected to the first, second and third motion transmitting means respectively.

8. Apparatus according to claim **6** wherein the force feedback means comprises first, second and third electric motors (**124**, **160** and **166**) connected to the first, second and third motion transmitting means respectively.

9. Apparatus according to claim **8** further including signal producing means connected to the first, second and third motion transmitting means respectively to produce electric output signals indicative of rotation of the first, second and third rotatable means about the first, second and third axes respectively, and the first, second and third electric motor means receive the electrical signals from the signal producing means to apply forces in accordance therewith to the first, a second and third motion transmitting means respectively.

10. A three degree of freedom hand controller which minimizes cross coupling between rotations about three mutually perpendicular axes by having the axes intersect at a point interior of the hand controller and which permits motions about the three axes to be transmitted exterior of the hand controller, comprising:

a first member (**46**) mounted on a first mechanical connection means (**42**) which rotates about the first axis;

a second member (**52**) gimbled to the first member and rotatable about the second axis, the second member including second mechanical connection means (**94**) connected thereto and extending exterior of the hand controller so as to transmit motion of the second member in a direction generally parallel to the first axis; and

a third member gimbled (**70**) to the second member and rotatable about the third axis, the third member including third mechanical connection means (**99**) connected thereto and extending exterior of the hand controller so as to transmit motion of the third member in a direction generally parallel to the first axis.

11. The hand controller of claim **10** further including first, second and third transducers (**142**, **160** and **166**) operable to convert mechanical motion to electrical output signals, each transducer mounted external to the hand controller and connected to one of the first, second and third mechanical connection means respectively.

12. The hand controller of claim **11** wherein the motion of the first mechanical connection means is rotary, the motions of the second and third mechanical connection means are linear and further including coupling means to convert the linear motions of the second and third connection means to rotary motions and wherein the first, second and third transducer are of the type which convert rotary motion to electrical signals.

13. The hand controller of claim **11** further including member means movable in at least one direction parallel to the plane of the second and third axes connected to the hand controller, motion of the hand controller in a direction parallel to the one direction causing movement of the member means in the one direction.

14. The apparatus of claim **13** wherein the first, second and third transducers are mounted on the member means.

15. The apparatus of claim **11** further including first, second and third force feedback means connected to the first, second and third mechanical connection means respectively to produce forces therein tending to oppose the motion of the first, second and third members about the first, second and third axes respectively.

16. The apparatus of claim **15** wherein the force feedback means comprises first, second and third scissor spring mechanisms (FIG. **5**).

17. The apparatus of claim **15** wherein the force feedback means comprises first, second and third electric motors (**124**, **160** and **166**) connected to receive the electric signals and produce forces in accordance therewith.

18. A three degree of freedom controller including hand grip means having an interior cavity (**39**) therein;

first mechanical motion transmitting means (**42**) rotatable about a first axis and extending from inside the cavity to a position remote from the hand grip means;

a first yolk fixed to the first mechanical motion transmitting means and in the cavity, the first mechanical motion transmitting means operable to transmit motion to and from the first yolk about the first axis;

a second yolk gimbled to the first yolk for rotation in the cavity about a second axis perpendicularly intersecting the first axis at a point;

a third yolk gimbled to the second yolk for rotation in the cavity a bout a third axis perpendicularly intersecting the first and second axes at the point;

second mechanical motion transmitting means (**94**) connected to the second yolk inside the cavity and extending remote from the grip to transmit motion to and from the second yolk about the second axis; and

third mechanical motion transmitting means (**99**) connected to the third yolk inside the cavity and extending remote from the grip to transmit motion to and from the third yolk about the third axis.

19. Apparatus according to claim **18** further including transducing means located remote from the grip, connected to the first, second and third mechanical motion transmitting means respectively and operable to produce first, second and third electrical signals indicative of the motions of the first, second and third yolks about the first second and third axes respectively.

20. Apparatus according to claim **19** further including member means mounted for movement in at least a first direction parallel to the plane of the second and third axes, the member means connected to carry the grip and having the transducing means mounted therein.

21. Apparatus according to claim **20** wherein a force imparted to the grip and directed generally through the point produces motion of the member means along the first direction.

22. Apparatus according to claim **19** further including force feedback means connected to the first, second and third mechanical motion transmitting means to provide motions thereto of magnitude corresponding to the electrical signals from the first, second an third transducing means and of direction to oppose any motions of the first, second and third yolks about the first, second and third axes respectively.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,142,931

DATED : September 1, 1992

INVENTOR(S) : ISRAEL MENAHEM

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 10, line 31, delete "transducer", insert "transducers"

Col. 11. line 5, delete "a bout", insert "about"

Signed and Sealed this

Twenty-first Day of December, 1993

Attest:

Bruce Lehman

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks